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The Grimsel in-situ stimulation project

on the seismo-hydro-mechanical response during hydraulic stimulation tests

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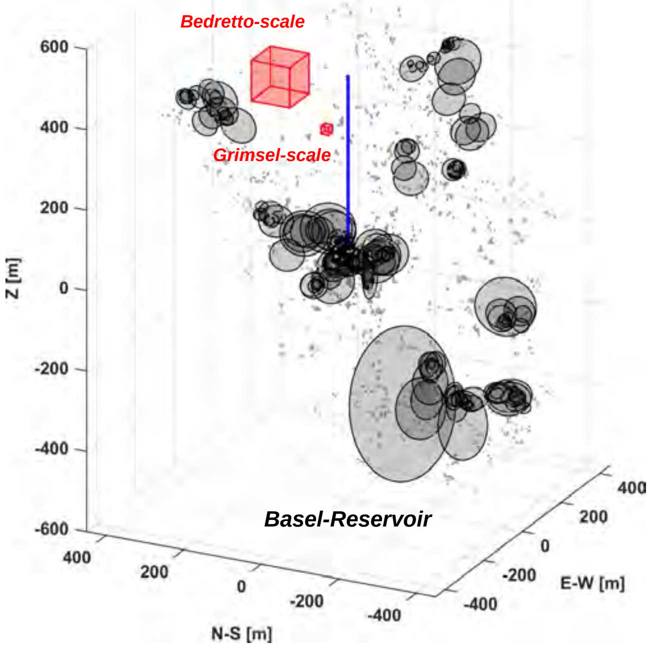
SCCER SoE

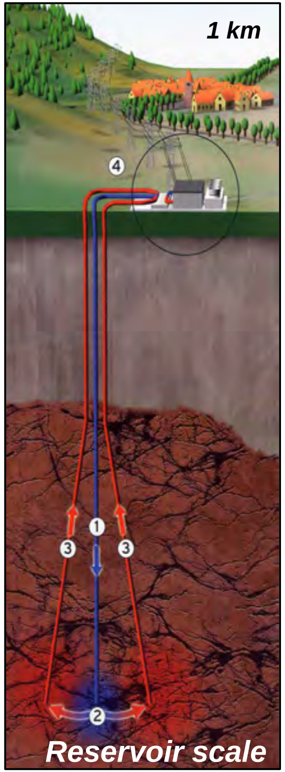
Why do we need in-situ experiments?

Main research question: How can we **create an efficient heat exchanger** while keeping the risk of **induced earthquakes at acceptable levels**?

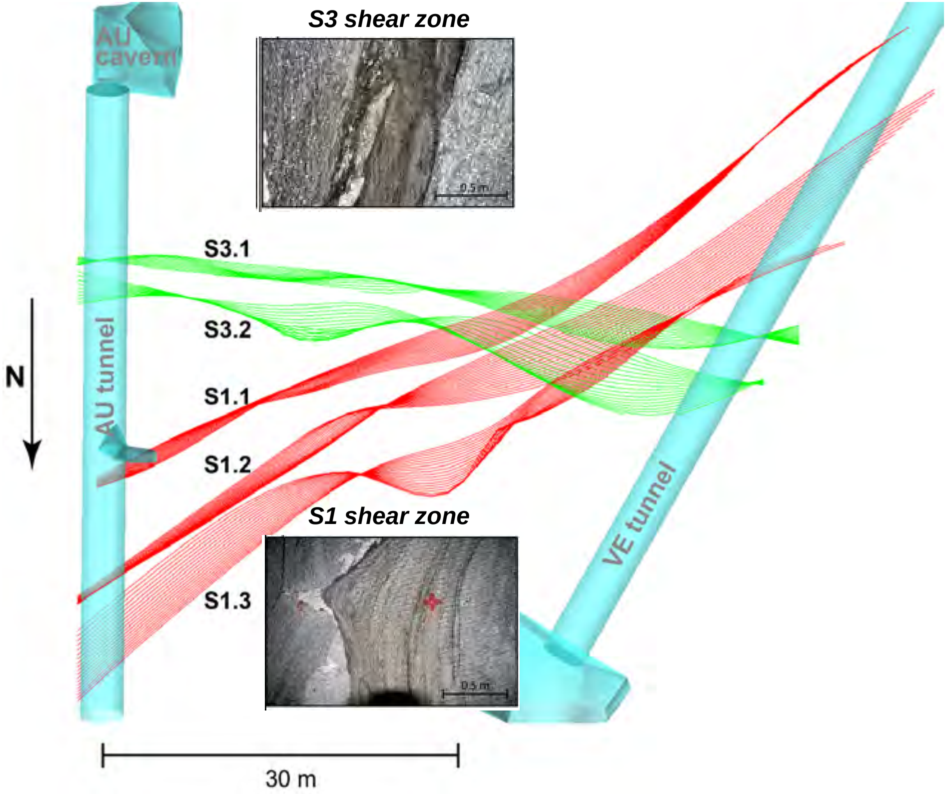
Difficulty to control and access

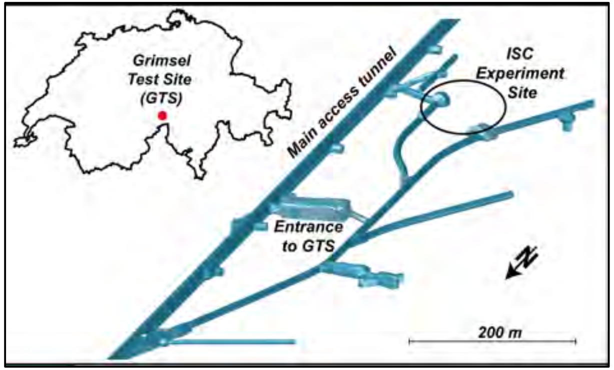


Scaling questionable

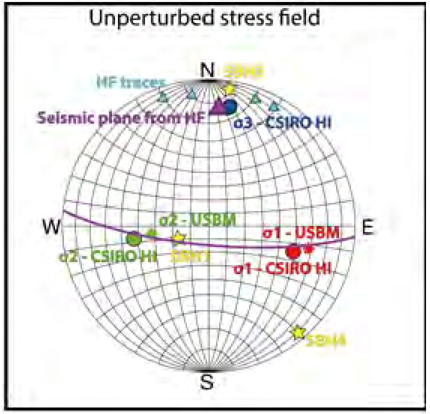


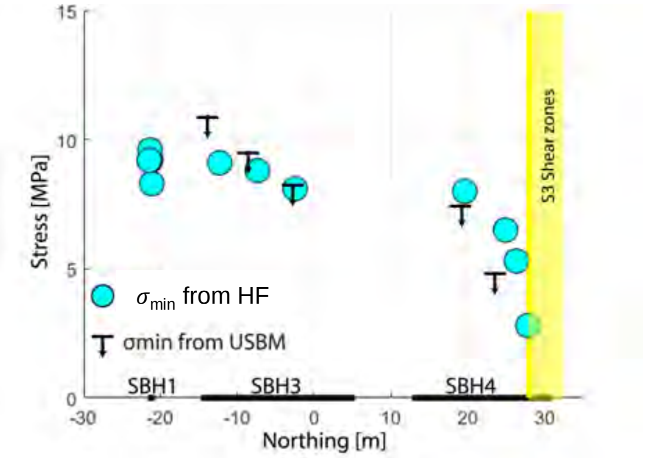
Grimsel Test Site and the In-situ Stimulation Experiment

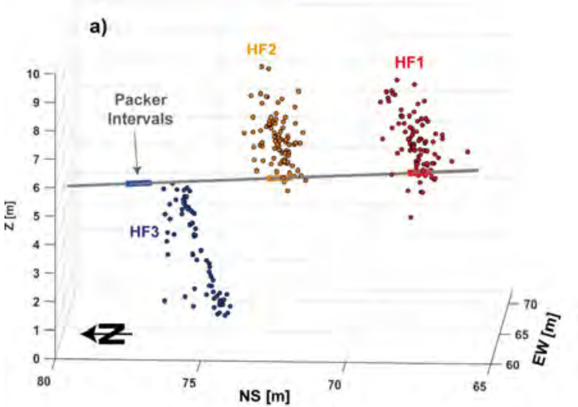




Preparation: in-situ stress measurements





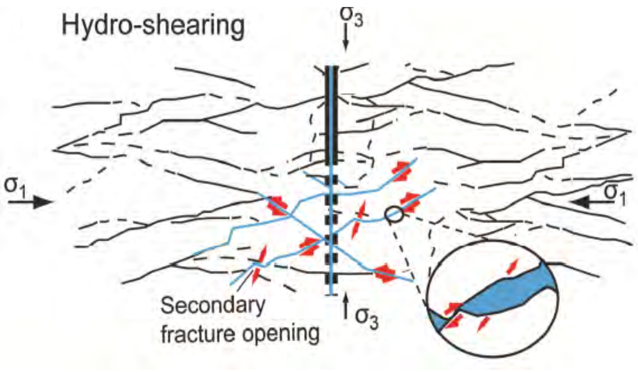


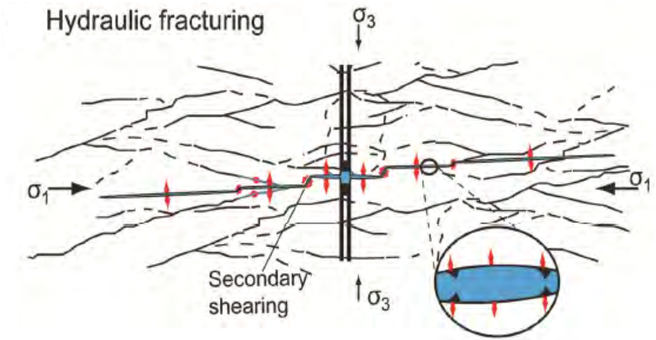
- Stress field influenced by topography
- Stress field is heterogeneous with σ_3 reducing towards shear zone
- Combination of methods important (overcoring, hydraulic fracturing with seismic monitoring)

Krietsch 2018, RMRE; Gischig 2018, Solid Earth; Jalali 2018, GRL

Stimulation concept

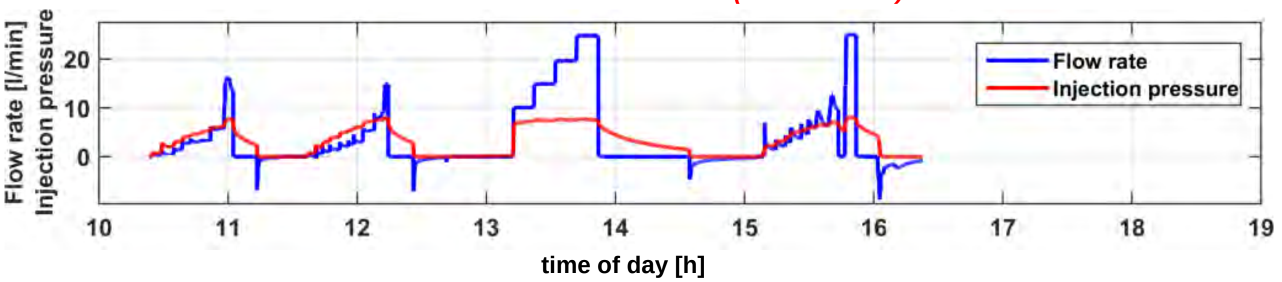
- 6 Hydroshearing (HS) experiments (Feb. 2017), 6 Hydrofracturing (HF) experiments (May 2017)



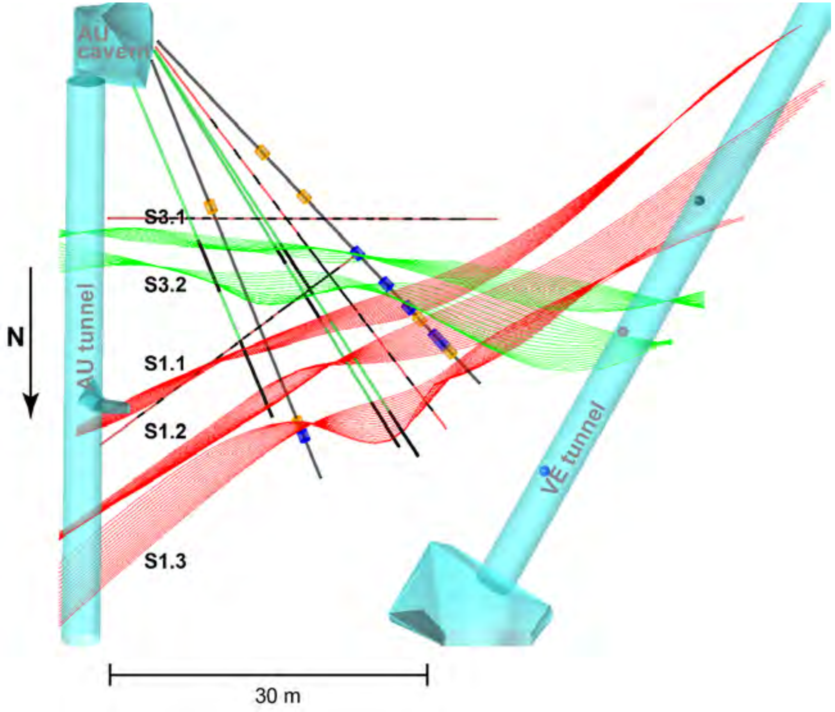


Stimulation concept

- 6 Hydroshearing (HS) experiments (Feb. 2017), 6 Hydrofracturing (HF) experiments (May 2017)
- Standardized injection protocol (one each for HS and HF)
- Injected volume ~ 1 m^3 in each experiment
- Variability in observations due to geology, not injection strategy



Stimulation experiments: Injection and observation setup



6 Hydroshearing intervals
6 Hydrofracturing intervals

60 Strain sensors
3 Tilt sensors

8 Pressure observation intervals

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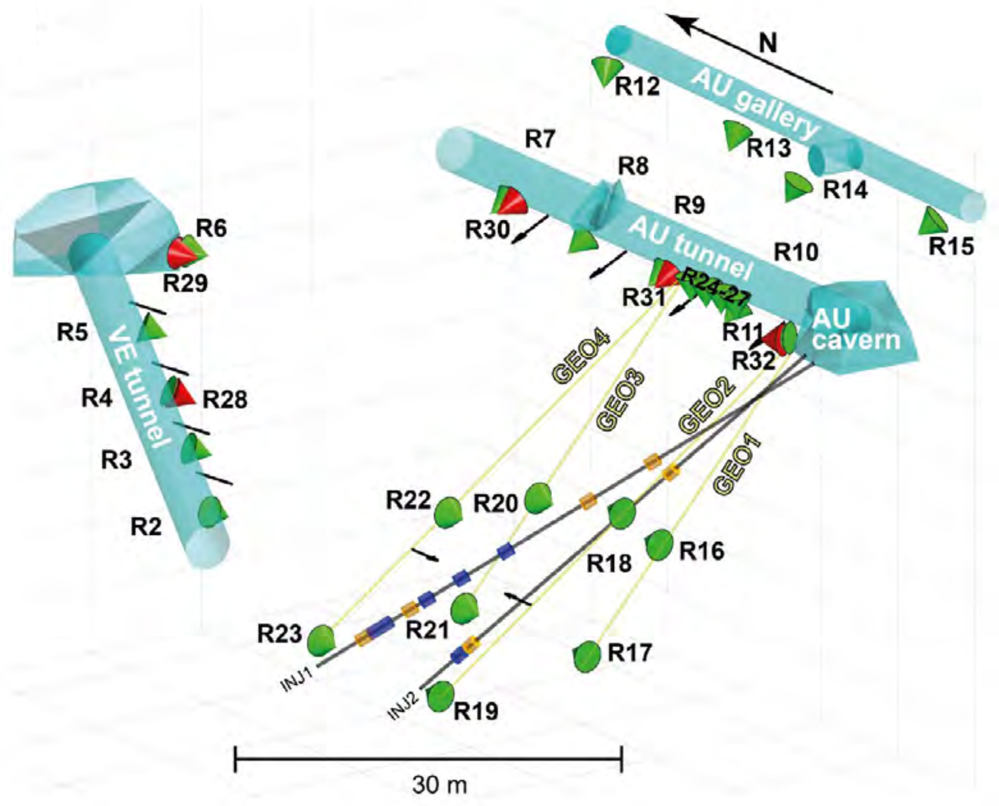
Seismic monitoring

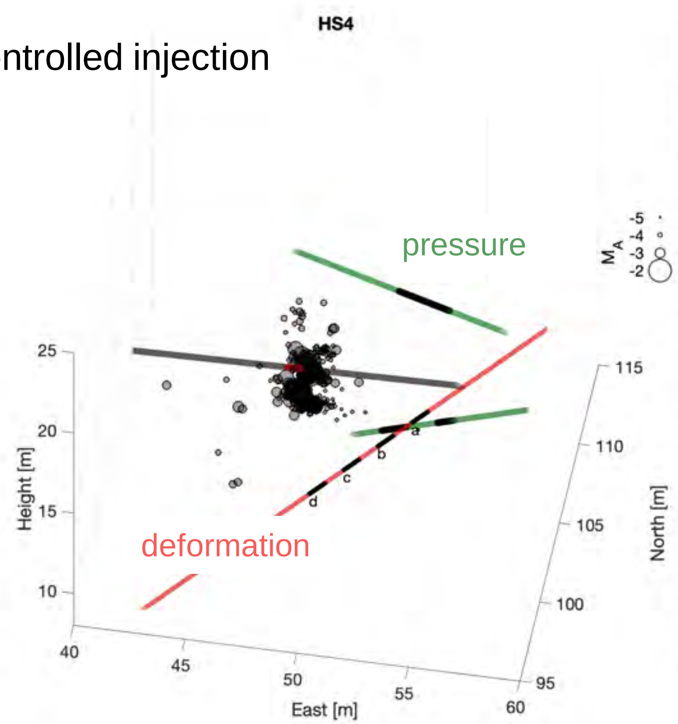
- 26 AE sensoren
  (8 in boreholes)
- 5 accelerometers

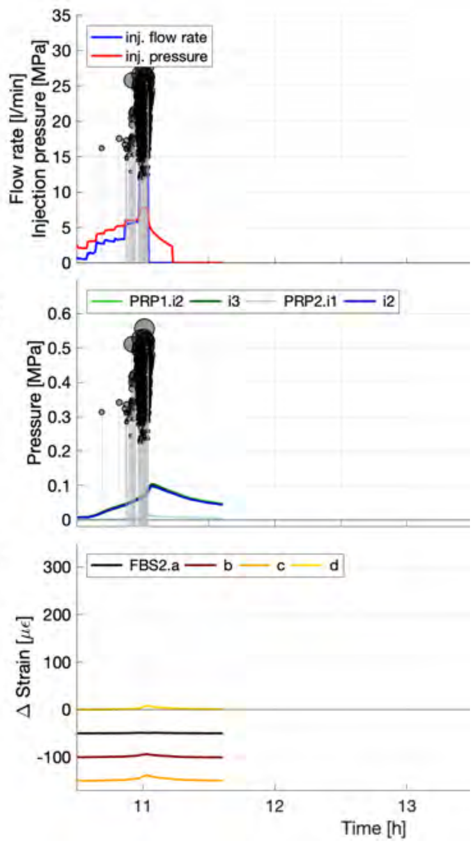
- 20’824 detected microseismic events
- 5’456 manually picked and located events
- Location accuracy: 0.5 m
- Magnitude range
  Mr –4.0 to –1.5

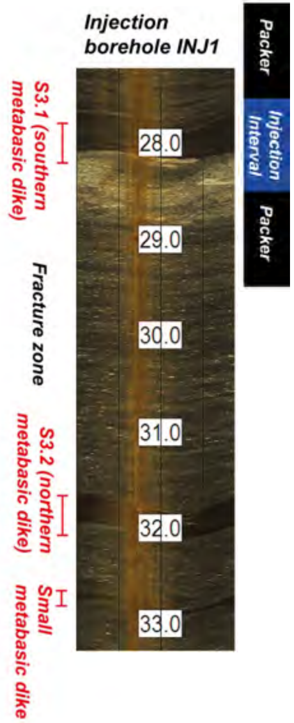


Example hydroshearing experiment: cycle 1

pressure-controlled injection

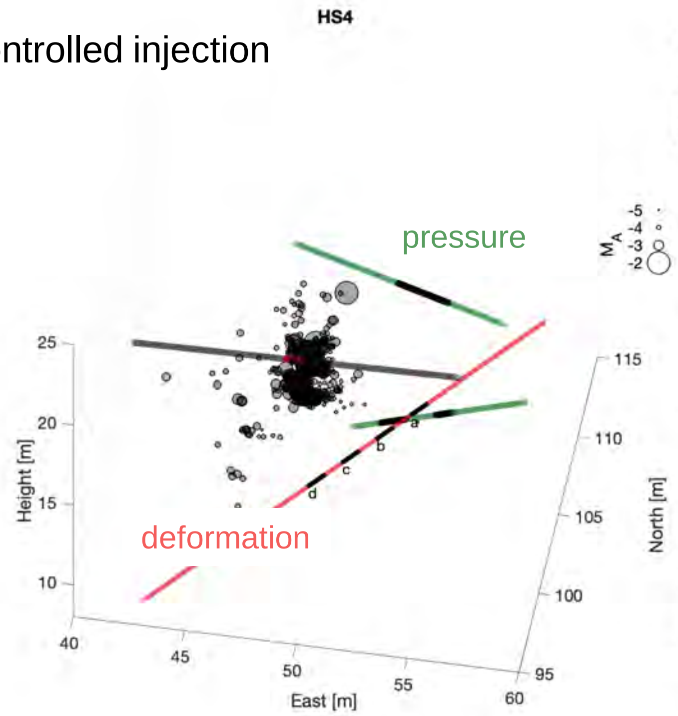


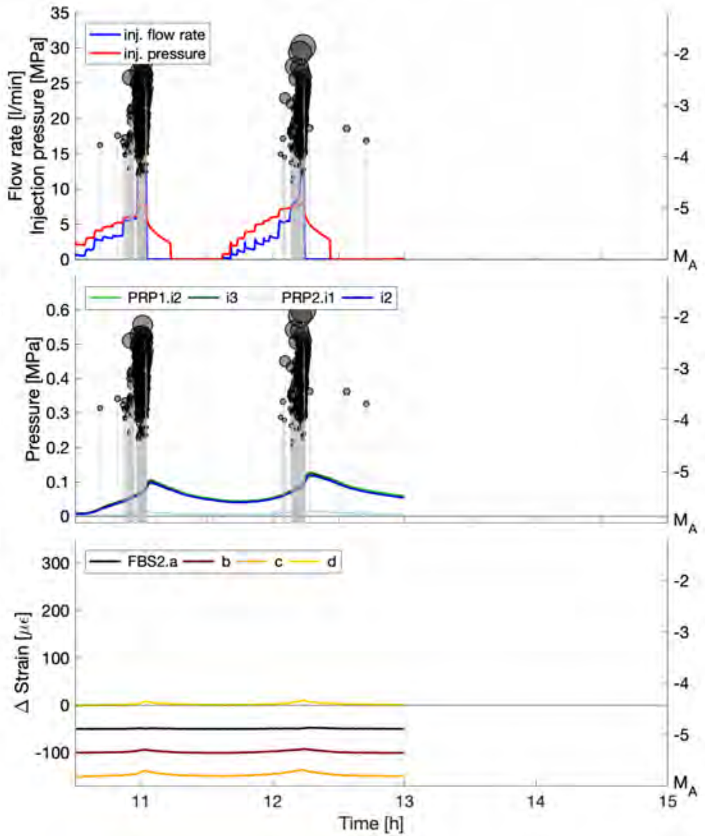




Example hydroshearing experiment: cycle 2

pressure-controlled injection





Example hydroshearing experiment: cycle 3

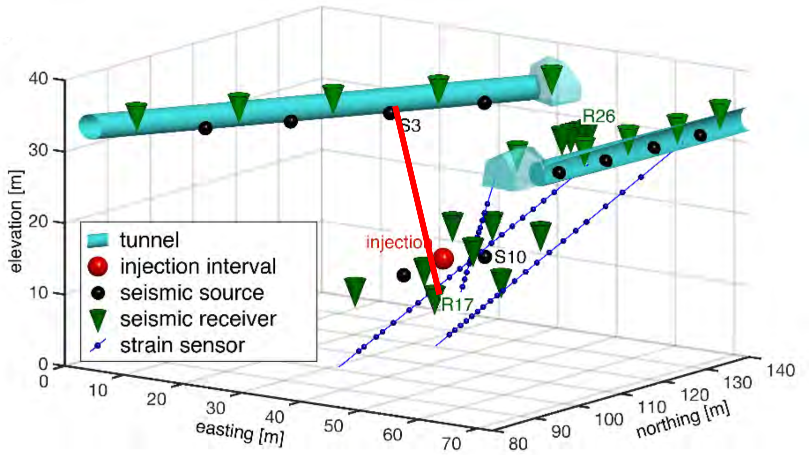
rate-controlled injection

Example hydroshearing experiment: cycle 3

rate-controlled injection

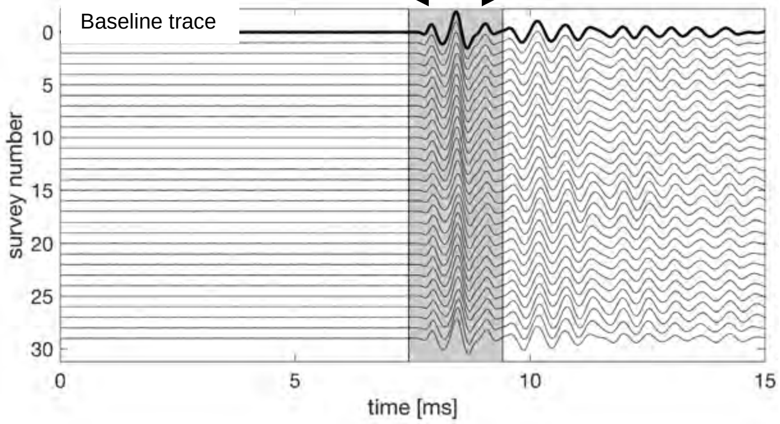
Active seismic monitoring

- Repeated surveys (every ~10 min) using 10 sources
- Highly repeatable signals
- Correlation analysis to extract variation in first arrivals



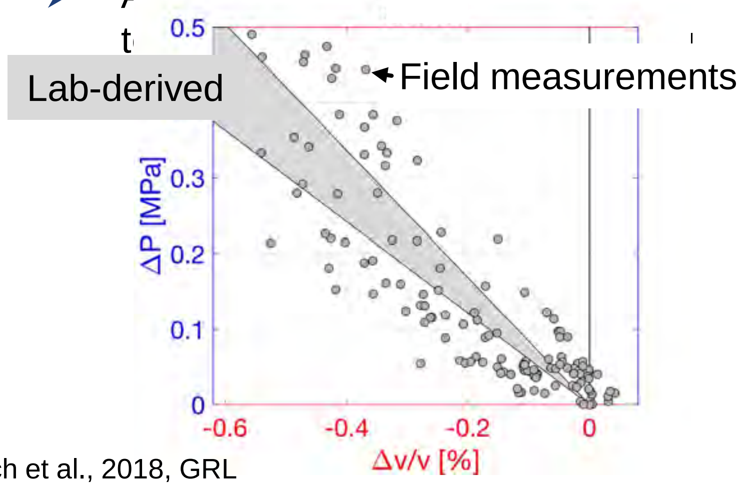

Hammer source


Borehole sensor

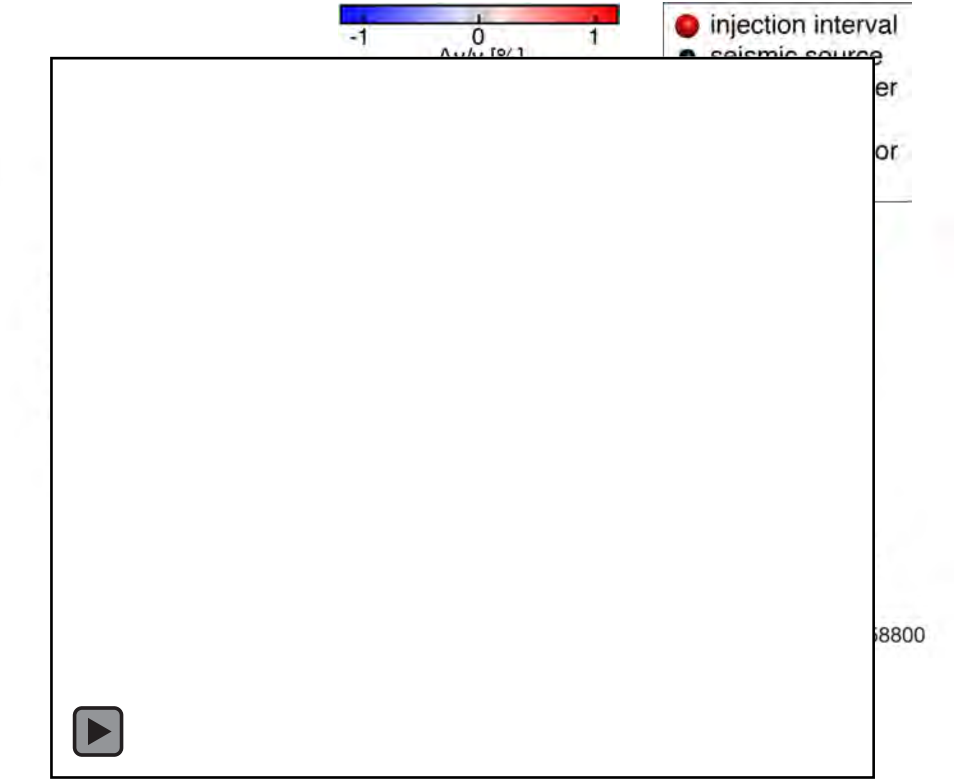


Pressure monitoring from seismic velocity observations

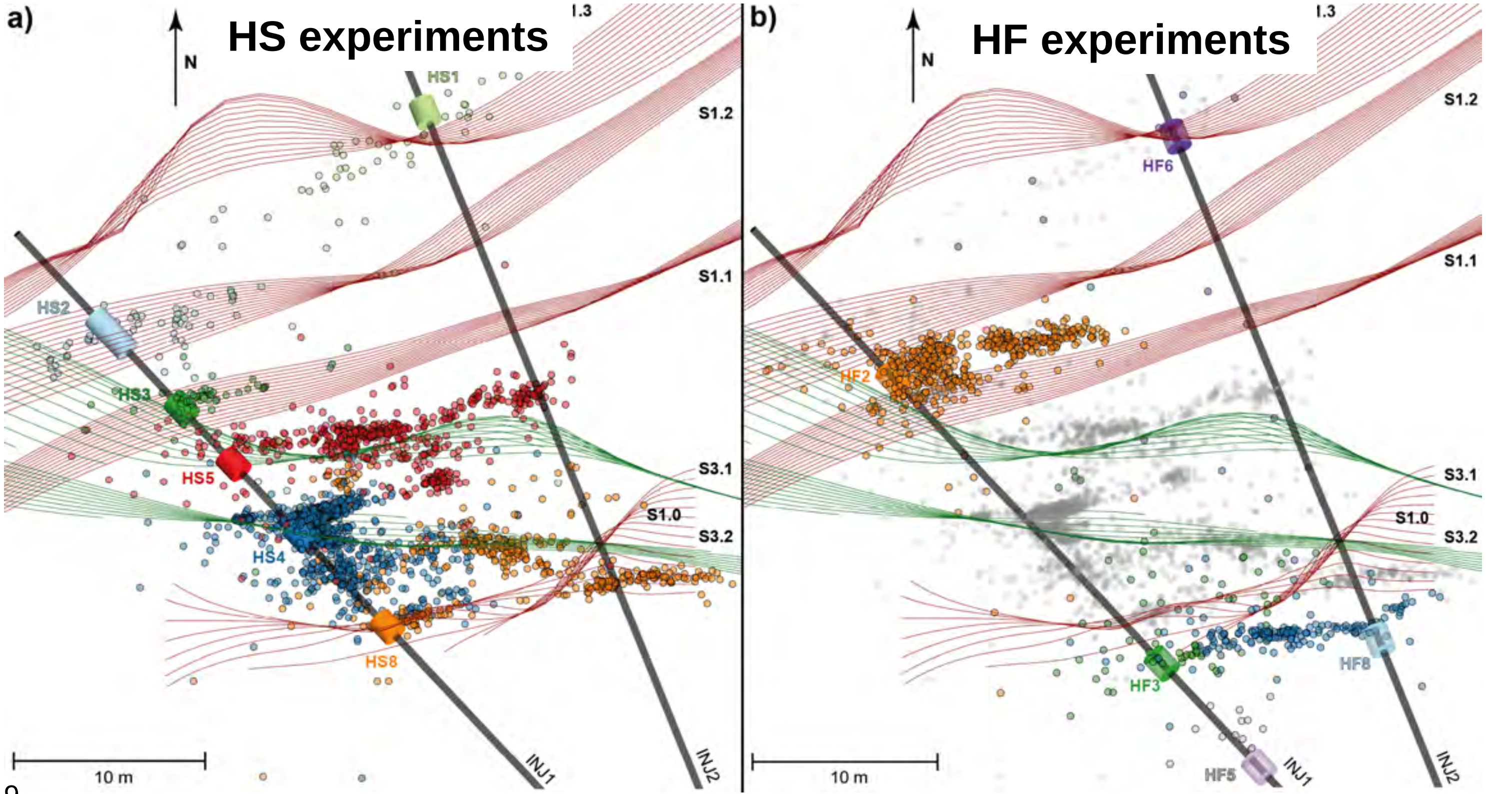
- Repeated seismic surveys during hydraulic stimulations show decrease of velocity
- Laboratory and field measurements show strong correlation between seismic velocity and pore pressure



Doetsch et al., 2018, GRL



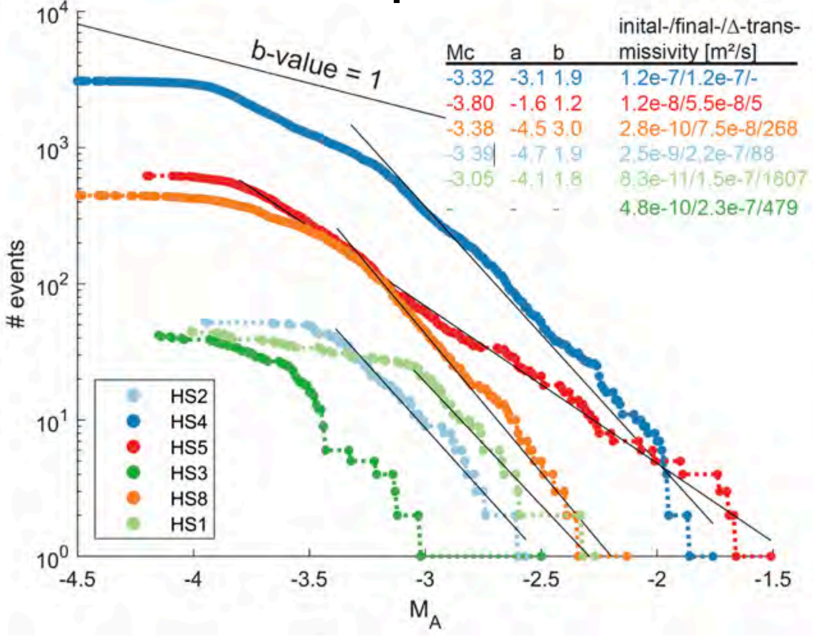
Seismicity of all twelve experiments



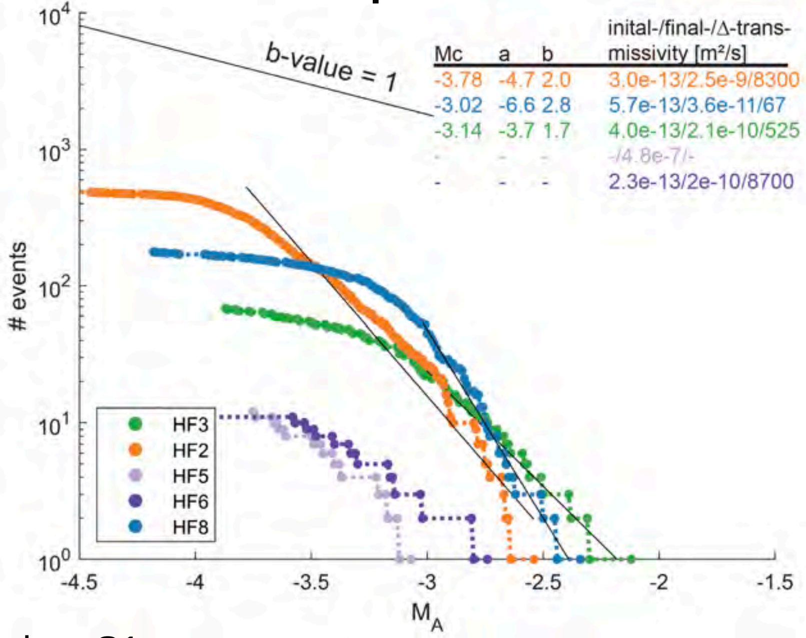
Villiger et al., 2019

Frequency magnitude distributions

HS experiments



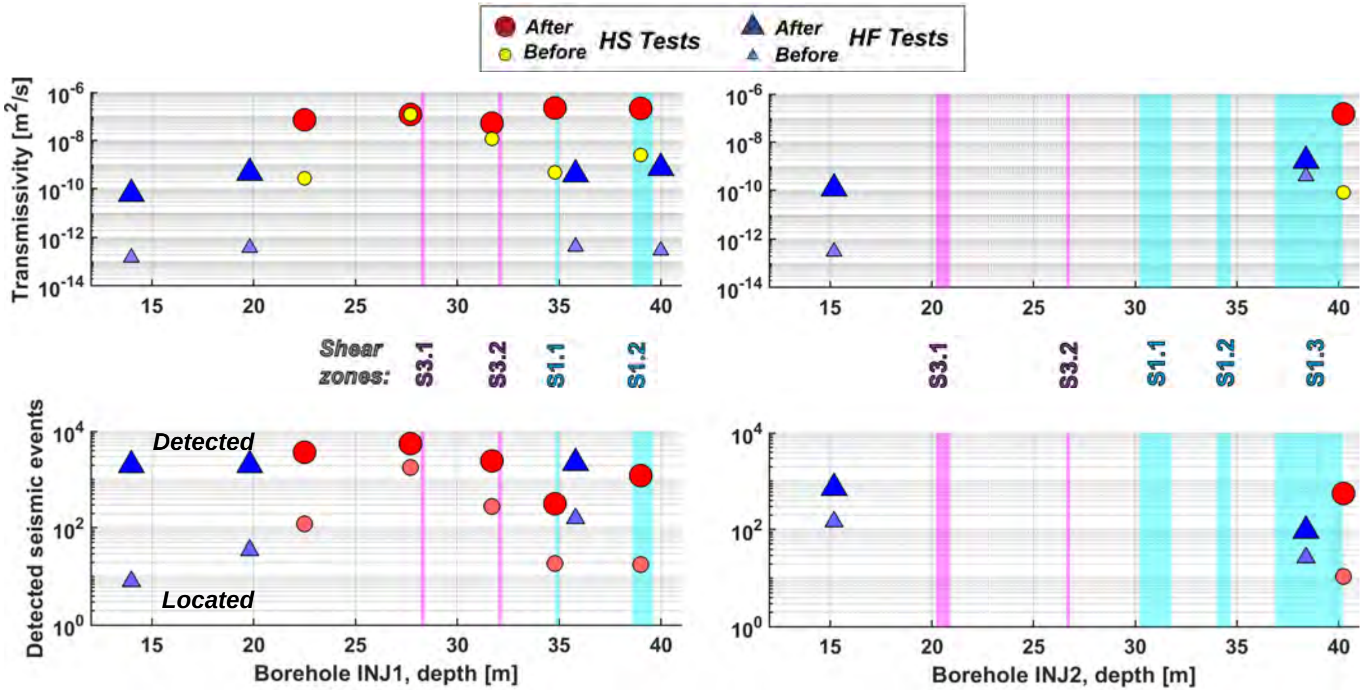
HF experiments



- S3 shear zone more seismogenic than S1
- Most b-values between 1.7 and 2

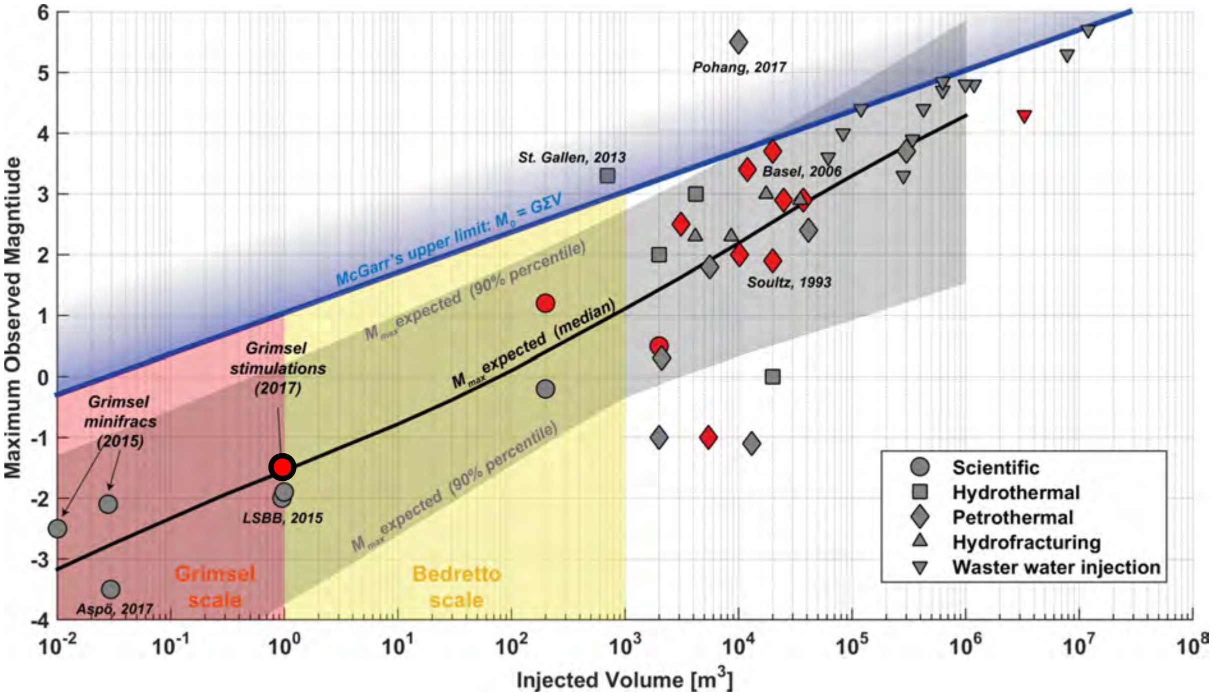
Villiger et al., 2019

Change in hydraulic properties



- Transmissivity increase by factor of 1 to 1000
- Final transmissivity similar for all HS experiments
- Final transmissivity of all HF experiments much smaller than for HS

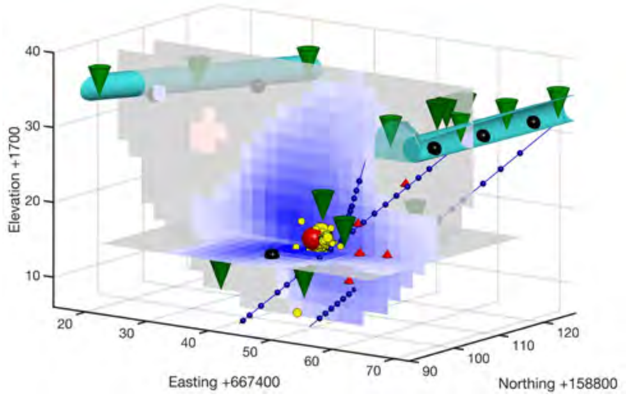
Seismic hazard and maximum magnitude

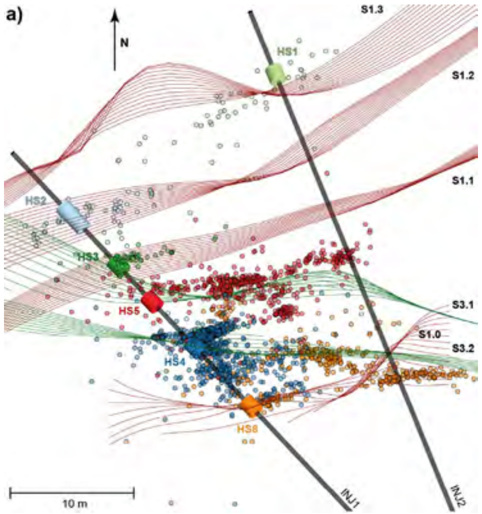


- Maxiumum magnitude of M = -1.5
- Maximum expected magnitude ≈ maximum observed magnitude
- ➢ New data in scale with few previous experiments

Summary Grimsel ISC

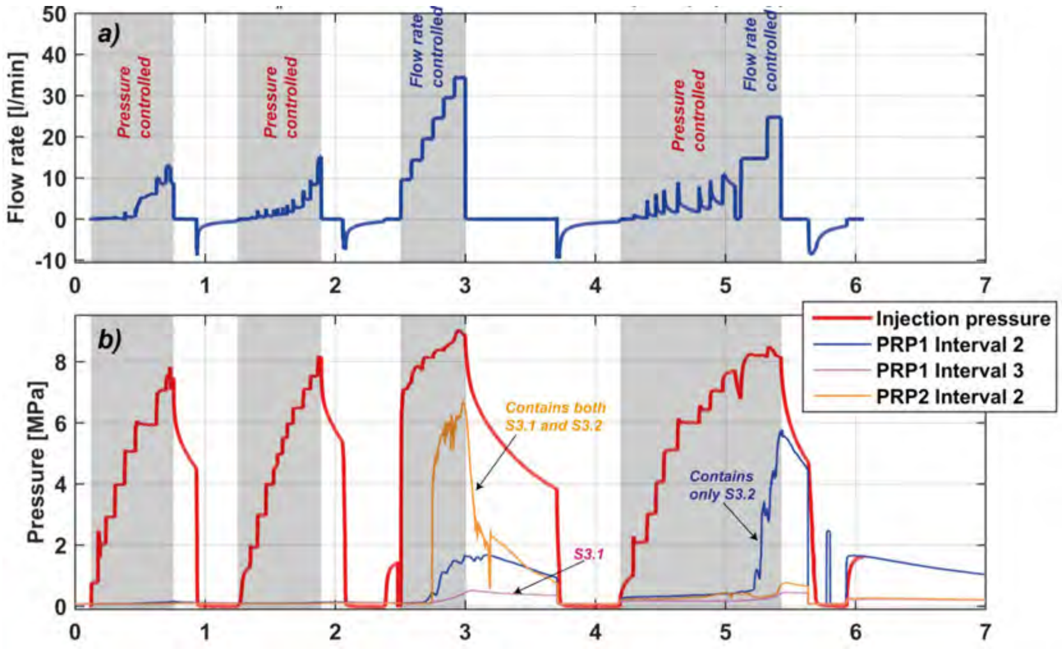
- Scaled 20-m experiment allows monitoring with high level of detail
- Successful hydraulic stimulations with high increase in transmissivity
- Strong correlation between shearing and increase in transmissivity
- Negative correlation between seismicity and transmissivity/shearing
- Complex interplay between hydraulic fracturing and hydraulic shearing
- Pressure propagation: linear, non-linear and channelized flow observed during stimulations
- Active seismic observations allow pressure monitoring

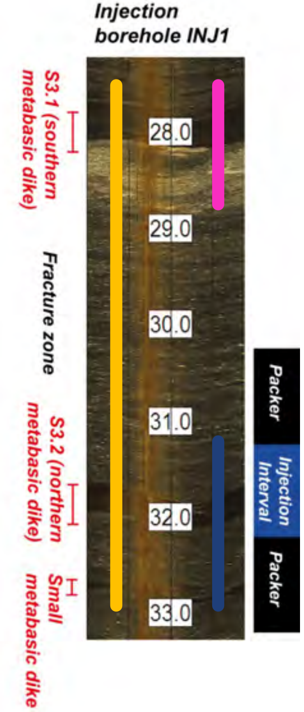




Thank you for your attention!

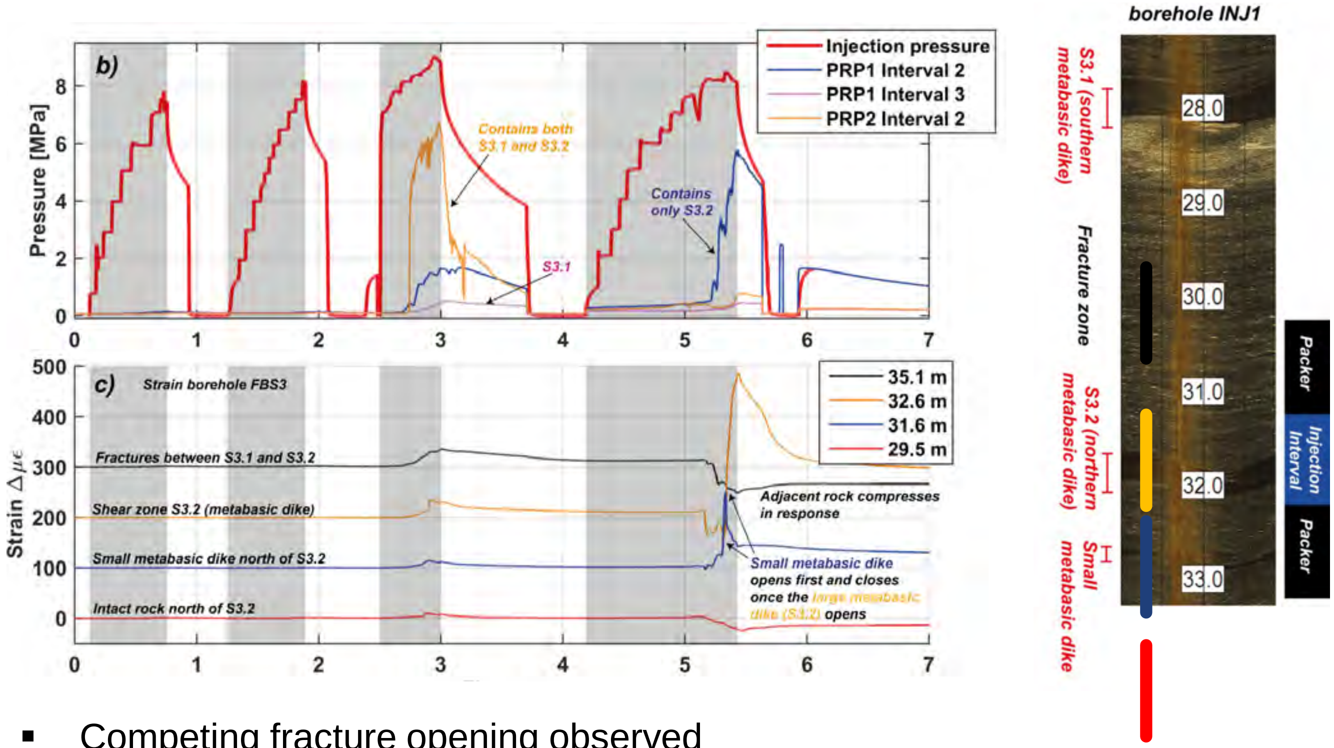
Example hydroshearing experiment: pressure propagation





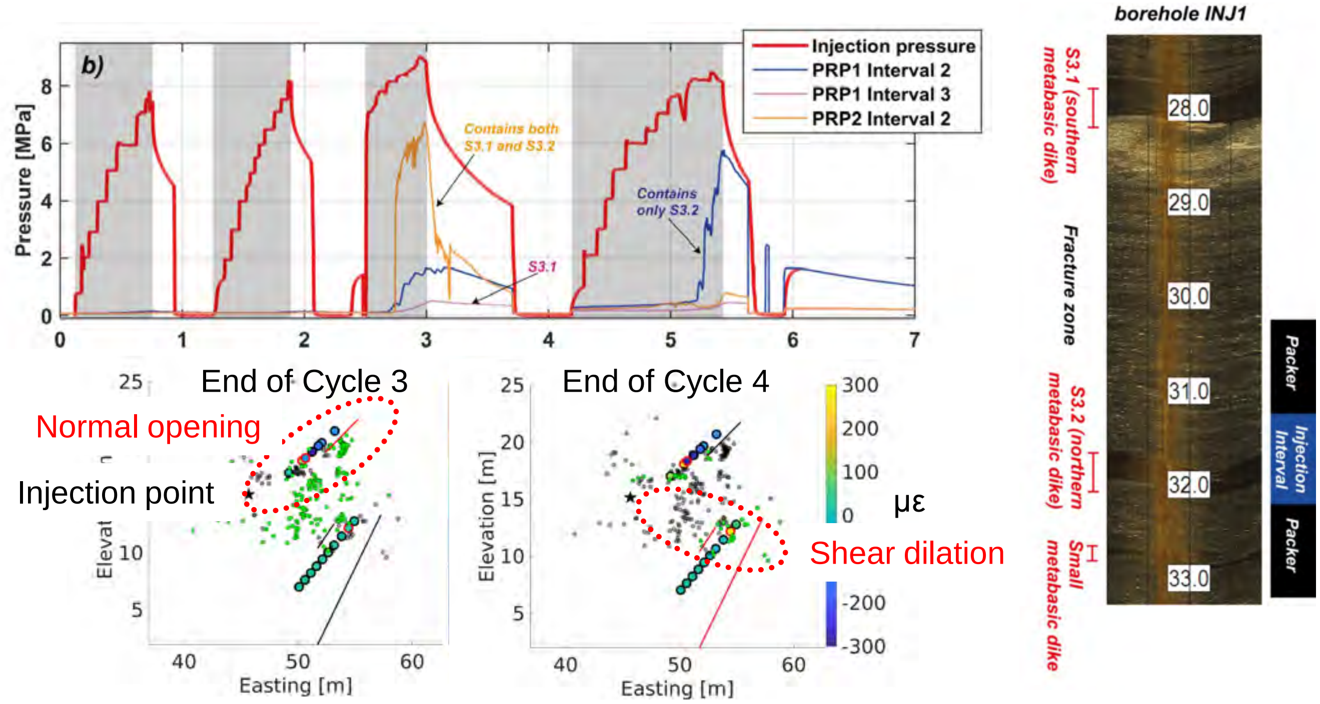
- Pressure pulses observed (only in this experiment)
- ➢ Strongly heterogeneous, channelized flow
- ➢ Flow paths changing during experiment

Example hydroshearing experiment: fracture opening



- Competing fracture opening observed
- Local stress transfer due to fracture opening

Example hydroshearing experiment: fracture opening



- Competing fracture opening observed
- Local stress transfer due to fracture opening
- Interplay between hydraulic fracturing and shearing